# Search for new physics with high $p_T$ leptons

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**Abstract.** We discuss the results of searches for new physics phenomena with high $p_T$ leptons in the final state, using pp collisions at 7 TeV delivered by LHC and collected with the CMS detector in 2010. Several of these early searches allow to set the most stringent limits on potential new physics phenomena such as new gauge bosons or leptoquarks. The analyses will be discussed, methods to determine background from data and the determined limits are presented. The results demonstrate good understanding of the detector and backgrounds in a variety of channels.

**Keywords:** W', Z', leptoquark, exotica
**PACS:** PACS number

## INTRODUCTION

This paper presents the results of searches for new physics phenomena beyond the Standard Model (SM) in proton-proton collisions at $\sqrt{s} = 7\ TeV$ delivered by the LHC and collected with the Compact Muon Solenoid (CMS [1]) detector in 2010. All these searches use the full 2010 dataset, corresponding to an integrated luminosity of 36 $pb^{-1}$. The analysis presented are characterized by the presence of one or more high $P_T$ leptons (electrons and muons) in the final state coming from the decay of an hypothetical massive particle such as W', Z' or leptoquark (LQ).

## HIGH-$P_T$ LEPTONS AT CMS

The reconstruction of electrons and muons at high energies presents several experimental issues. Electrons are reconstructed as energy deposits in the electromagnetic calorimeter linked to a track in the tracker. The identification criteria, based on the shape of the electromagnetic shower, track matching and isolation, are optimized for high energy electrons in order to keep an high efficiency and to guarantee a low rate of jets faking electrons. Concerning the muon reconstruction, the Muon System and Tracker alignment plays an important role, because it has a direct impact on the mass resolution. There are two important issues which are peculiar for the TeV muon reconstruction: the first is the low bending in the magnetic field at such high energies which requires a very precise measurement of the position and the second one is the high probability of bremsstrahlung. Dedicated algorithms have been developed in order to get the best performances in terms of efficiency and resolution.
Lepton reconstruction and identification efficiencies are measured using the so called "Tag and probe" method, which exploits Drell-Yan events: in events containing two electron (muon) candidates, one lepton is reconstructed with tight criteria and used as

"tag", the second one is identified as "probe"; in this way, a sample of high purity probes can be selected and used to measure efficiencies.

## Z' AND W' SEARCH

Several theoretical models predict, in addition to the well known electroweak vector bosons $\gamma$, W and Z, further heavy gauge bosons such as Z' and W'. The sensitivity to searches of new heavy bosons is usually explored using a benchmark model, the Reference Model by Altarelli et al. [2], in which the W' and the Z' are a carbon copy of the SM W and Z bosons with the same left-handed fermionic couplings. Thus, the decay modes and branching fractions are similar to those of the W and Z bosons. Decays of the heavy vector bosons into the Standard Model bosons W and Z are suppressed in this model. A list of references for such theories can be found in [3]. The CMS collaboration has searched for such narrow resonances in the invariant mass spectrum of dimuon and dielectron [4] final states, as well as in the transverse mass spectrum of electron+neutrino [5] and muon+neutrino [6] final states.

Z' $\to l^+l^-$ events are characterized by two high transverse momentum leptons with opposite charge. For both dimuon and dielectron final states, two isolated same flavour leptons that pass the lepton identification criteria are required. The two charges are required to have opposite sign and for the muon channel each event is required to have the three-dimensional opening angle between the two muons to be smaller than $\pi - 0.02$ radiants. This requirement provides protection against cosmic ray muons. The main SM process that contributes to the dimuon and dielectron invariant mass spectra is Drell-Yan production ($Z/\gamma^*$); there are also contributions from the $t\bar{t}$, tW, WW, and $Z \to \tau\tau$ channels. Especially for the electron channel, jets may be misidentified as leptons and contribute to the dilepton invariant mass spectrum through multi-jet and vector boson + jet final states.

In the W' analysis, in addition to the lepton identification requirements, two kinematic selection ensure the balance between the lepton and the Missing Transverse Energy (MET) both in module and in direction ($0.4 < E_T/MET < 1.5$ and $\Delta\phi(ele,MET) < 2.5$). For the electron and the muon channel, two different solutions were adopted to estimate the SM background in the signal region of the transverse mass ($M_T$) distribution. For the electron channel the shape of the W from MC is corrected to take into account the differences in the MET resolution and response between data and MC that can arise due to un-modeled detector effects, then the corrected shape is used, together with the template of the multi-jet background obtained from non-isolated electrons, to perform a simultaneous fit of the $E_T/MET$ distribution and determine the normalization of the two main backgrounds. In the muon channel analysis, instead, a sideband fit of the transverse mass distribution in data is performed in a region where the signal contamination is smaller than 1%. The function obtained is used to extrapolate the background estimation in the high $M_T$ region.

The spectra are consistent with standard model expectations in both the bulk and the tails of the aforementioned distributions. Figure 1 shows the 95% confidence level (CL) upper limits on the cross section of Z' (W') production, obtained combining the di-electron (electron+neutrino) and dimuon (muon+neutrino) channels. A Z' (W') with

SM-like coupling can be excluded below 1.14 (1.58) TeV. Model-independent lower limits on the Z' mass have also been reported in [4] as a function of the couplings of the Z' to fermions in the annihilation of charge 2/3 and charge -1/3 quarks.

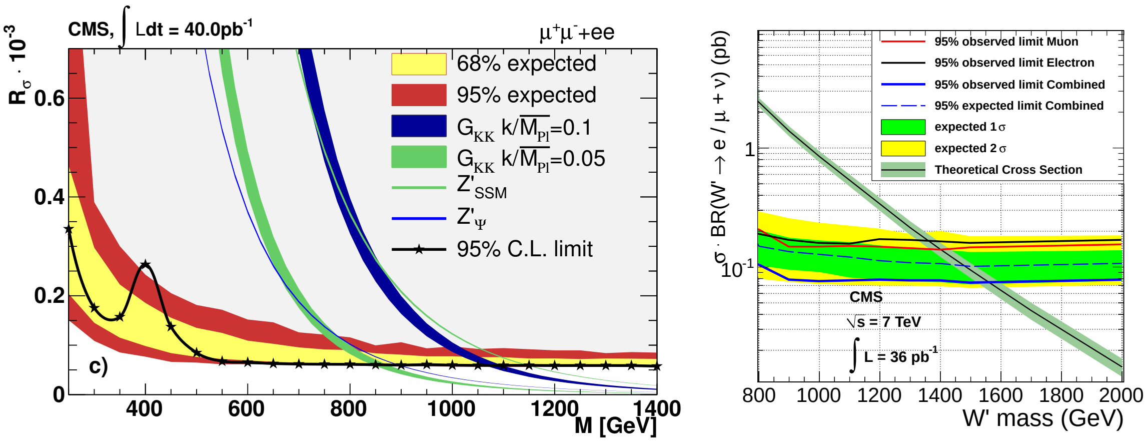


**FIGURE 1.** (Left) The upper limits as a function of resonance mass $M$, on the production ratio $R_\sigma$ of cross section times branching fraction into lepton pairs for $Z'_{SSM}$ and $G_{KK}$ production and $Z'_\psi$ boson production. The limits are shown from the combined dilepton result. The predicted cross section ratios are shown as bands, with widths indicating the theoretical uncertainties. (Right) Upper limits as a function of the resonance mass on the W' cross section for the individual electron+neutrino and muon+neutrino channels, and their combination.

## LEPTOQUARKS SEARCH

The standard model has an intriguing but ad hoc symmetry between quarks and leptons. In some theories beyond the SM, such as SU(5) gran unification, Pati-Salam SU(4), and others, the existence of a new symmetry relates the quarks and leptons in a fundamental way. These models predict the existence of new bosons, called leptoquarks. The leptoquark (LQ) is coloured, has fractional electric charge, and decays to a charged lepton and a quark with unknown branching fraction $\beta$, or a neutrino and a quark with branching fraction (1 - $\beta$). Constraints from experiments sensitive to flavour-changing neutral currents, lepton-family-number violation, and other rare processes favour LQs that couple to quarks and leptons within the same SM generation, for LQ masses accessible to current colliders. Searches for pair-production of first and second generation scalar LQs have been performed in the eejj [7], e$\nu$jj [8], and $\mu\mu$jj [9] channels. The dominant backgrounds for these searches arise from the SM production of $Z/\gamma + jets$, W+jets and $t\bar{t}$ events. The reconstructed variable $S_T$, defined as the scalar sum of the transverse momenta of the two leading (in $p_T$) charged leptons and jets, has a large signal-to-background discrimination power, and it is used to select LQ candidate events. Figure 2 shows the exclusion limits at 95% CL on the first generation leptoquark hypothesis in the $\beta$ versus LQ mass plane for the eejj and e$\nu$jj channels, and their combination. First generation scalar LQ masses below 384 GeV (340 GeV) are excluded at 95% CL for $\beta$ = 1 ($\beta$ = 0.5). In the $\mu\mu$jj channel, a 95% CL lower limit on the second generation scalar LQ mass is set at 394 GeV assuming $\beta$ = 1.

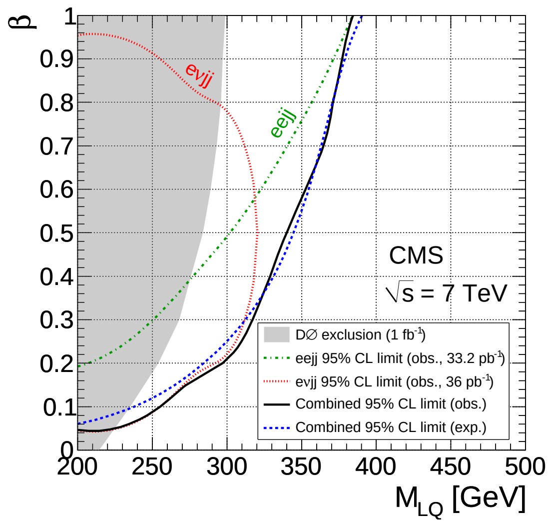


**FIGURE 2.** Exclusion limits at 95% CL on the first generation LQ hypothesis in the $\beta$ versus LQ mass plane. The shaded region is excluded by the current D0 limits, which combine results of eejj and e?jj decay modes.

## CONCLUSIONS

The CMS experiment has searched for evidence of different models of new physics in several channels using the 2010 LHC dataset and has already explored new territory beyond the Tevatron. The early data analysis has been crucial to understand the detector behavior and the backgrounds in a variety of channels. No evidence for new physics signature has yet been observed.

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